

ASBESTOS FIBER REENTRAINMENT DURING
DRY VACUUMING AND WET CLEANING OF
ASBESTOS-CONTAMINATED CARPET

by

John R. Kominsky
Ronald W. Freyberg
PEI Associates, Inc.
Cincinnati, Ohio 45246

EPA Contract No. 68-03-4006

Technical Project Monitor
William C. Cain

Project Officer
Thomas J. Powers

Water and Hazardous Waste Treatment Research Division
Risk Reduction Engineering Laboratory
Cincinnati, Ohio 45268

RISK REDUCTION ENGINEERING LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

The information in this document has been funded wholly or in part by the U.S. Environmental Protection Agency under Contract 68-03-4006 to PEI Associates, Inc. It has been subjected to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This report provides information on airborne asbestos fiber reentrainment during dry vacuuming and wet cleaning of asbestos-contaminated carpet under experimental conditions. Airborne asbestos concentrations were determined before and during carpet cleaning. Overall, airborne asbestos concentrations were two to four times greater during the carpet cleaning activity. The level of asbestos contamination and the type of cleaning method used had no statistically significant effect on the relative increase of airborne asbestos concentrations during carpet cleaning.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

ABSTRACT

A study was conducted to evaluate the potential for asbestos fiber reentrainment during cleaning of carpet contaminated with asbestos. Two types of carpet cleaning equipment were evaluated at two carpet contamination levels. Airborne asbestos concentrations were determined before and during carpet cleaning. Overall, airborne asbestos concentrations were two to four times greater during the carpet cleaning activity. The level of asbestos contamination and the type of cleaning method used had no statistically significant effect on the relative increase of airborne asbestos concentrations during carpet cleaning.

This document was submitted in fulfillment of Contract No. 68-03-4006 by PEI Associates, Inc., for the U.S. Environmental Protection Agency's Office of Research and Development, Risk Reduction Engineering Laboratory. This report covers a period of January 1988 to July 1989, and work was completed as of July 31, 1989.

CONTENTS

Foreword	iii
Abstract	iv
Figures	vi
Tables	vi
Acknowledgments	vii
1. Introduction	1
Background	1
Objectives	1
2. Conclusions and Recommendations	2
Conclusions	2
Recommendations	2
3. Study Design	3
Test facility	3
Experimental design	5
Sampling strategy	6
4. Materials and Methods	8
Selection of carpet	8
Selection of carpet cleaning equipment	8
Sampling methodology	9
Analytical methodology	9
Statistical analysis	9
5. Experimental Procedures	11
Prestudy air monitoring	11
Carpet contamination	11
Disposal of asbestos-containing material	17
Site cleanup	17
Poststudy air monitoring	18
6. Quality Assurance	19
Sample chain of custody	19
Quality assurance sample analyses	19
Spray-application technique	21
7. Results and Discussion	25
References	32
Appendix A - Chrysotile Fiber Size Distribution in the High- and Low-Concentration Ampules	33
Appendix B - Total Airborne Asbestos Structure Concentrations Before and During Carpet Cleaning for Samples Analyzed by Transmission Electron Microscopy	35
Appendix C - Structure Length Distributions of Airborne Asbestos Before and During Carpet Cleaning	40

FIGURES

<u>Number</u>		<u>Page</u>
1	Layout of test facility	4
2	Distribution of chrysotile fiber lengths in the low and high concentration aqueous asbestos suspensions	16
3	Fiber size distributions from preliminary study of asbestos dispersion by spraying	24
4	Average airborne asbestos concentrations before and during carpet cleaning	26
5	Comparative plot of cumulative percentages of airborne asbestos fibers during dry vacuuming and wet cleaning of carpet with asbestos fibers in the low and high concentration suspensions	29
6	Airborne asbestos concentrations for varying fiber lengths for samples collected during dry vacuuming and wet cleaning of carpet	30

TABLES

<u>Number</u>		<u>Page</u>
1	Experimental Design	5
2	Probability of Detecting a Statistically Significant Difference at the 5 Percent Level of Significance Between Two Groups of Airborne Asbestos Measurements	6
3	Summary of Prestudy Airborne Asbestos Concentrations in Test Facility	11
4	Summary of Results of Transmission Electron Microscopy Analyses for Low and High Concentration Ampules	15
5	Summary of Field and Laboratory Blank Analyses	20
6	Results of Replicate and Duplicate Sample Analyses	21
7	Results From Preliminary Study of Asbestos Dispersion by Spraying--Fibers and Fiber Bundles	22
8	Fiber Length Distributions From the Preliminary Study of Asbestos Dispersion by Spraying	22
9	Summary Statistics for Airborne Asbestos Concentrations Before and During Carpet Cleaning	27
10	Summary of ANOVA Results for Airborne Asbestos Concentrations Measured Before and During Carpet Cleaning	27
11	Structure Morphology Distribution for Air Samples Collected Before and During Carpet Cleaning	28
12	Comparison of TEM and PCM Analyses of Selected Air Samples	31

ACKNOWLEDGMENTS

This document was prepared for EPA's Office of Research and Development, Risk Reduction Engineering Laboratory, in fulfillment of Contract No. 68-03-4006. Mr. Thomas J. Powers, P.E., served as the EPA Project Officer. Mr. Powers also offered the invaluable suggestion of contaminating the carpet using an aqueous suspension of asbestos. Mr. William C. Cain served as the Technical Project Monitor for this project. The administrative efforts and support given by Mr. Roger Wilmoth of EPA's Office of Research and Development is greatly appreciated.

The technical assistance provided by Dr. Eric Chatfield of Chatfield Technical Consulting, Limited, in the preparation and characterization of the aqueous asbestos suspensions used to contaminate the carpet is gratefully acknowledged. Colonel Stephen F. Kollar, Commander, USAF, authorized the use of a building at Wright Patterson Air Force Base to conduct this research study. Administrative support from Behram Shroff, Douglas Post, and Suzette Smith of the U.S. Air Force is also acknowledged. Review comments and suggestions provided by William Burch, P.E., Larry Longanecker, Kin Wong, Ph.D., Elizabeth Dutrow, and Joseph Breen, Ph.D., of EPA's Office of Toxic Substances; and William McCarthy and Michael Beard of EPA's Office of Research and Development, is also appreciated. Jean Chesson, Ph.D., Chesson Consulting, provided statistical consultation and peer review. Christopher Frebis of Computer Sciences Corporation also provided a statistical review of this report.

John R. Kominsky, C.I.H., and Ronald W. Freyberg of PEI Associates, Inc., were the principal authors. Mr. Robert S. Amick, P.E., of PEI Associates, Inc., served as senior reviewer. Marty Phillips and Jerry Day of PEI Associates, Inc., performed the technical edit and copy edit, respectively.

SECTION 1

INTRODUCTION

BACKGROUND

Buildings that contain friable asbestos-containing materials (ACM) may present unique exposure problems for custodial workers. Under certain conditions, asbestos fibers can be released from fireproofing, acoustical plaster, and other surfacing material. The release of asbestos by aging and deteriorating ACM is known to be episodic and to relate to a myriad of factors, such as the condition and amount of asbestos present, the accessibility of the material, activity within the area, vibration, temperature, humidity, airflow, use patterns, etc. A major concern is the extent to which carpet and furnishings may be serving as reservoirs of asbestos fibers and what happens to these fibers during normal custodial cleaning operations.

OBJECTIVES

The U.S. Environmental Protection Agency (EPA) performed a series of controlled experiments in an unoccupied building to evaluate the effectiveness of a high-efficiency particulate air (HEPA)-filtered vacuum cleaner and a HEPA-filtered hot-water extraction cleaner in the removal of asbestos from carpet, and to evaluate the potential for reentrainment of asbestos fibers during carpet-cleaning activities. The study was designed to compare carpet asbestos concentrations before and after cleaning with each cleaning method at two known contamination levels. Work area airborne asbestos concentrations before and during carpet cleaning were also compared.

This report presents only air monitoring results from dry vacuuming and wet cleaning of asbestos-contaminated carpet to evaluate the potential for fiber reentrainment during cleaning. The results of the carpet sample analyses and the effectiveness of two cleaning methods in the removal of asbestos fibers from contaminated carpet are presented in a separate report.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Both dry vacuuming and wet cleaning of carpet artificially contaminated with asbestos fibers resulted in a statistically significant increase in airborne asbestos concentrations. The increase did not vary significantly with the type of cleaning method (wet or dry) or with the two levels of asbestos contamination applied to the carpet. While this research observed significant increases in airborne asbestos concentrations during cleaning activities in a controlled study under artificial, simulated conditions, it is not known if such increases occur in real-world custodial operations. Obviously, this possibility is a concern.

RECOMMENDATIONS

This research suggests that normal custodial cleaning of asbestos-contaminated carpet may result in elevated airborne asbestos concentrations. Further research is needed to determine actual exposure risk to custodial workers performing these activities in buildings containing friable asbestos-containing materials.

SECTION 3

STUDY DESIGN

TEST FACILITY

This study was conducted in an unoccupied building at Wright-Patterson Air Force Base in Dayton, Ohio. Two rooms, each containing approximately 500 square feet of floor space, were constructed in a larger bay of the building.

Figure 1 presents the layout of the test facility. The rooms were constructed of 2-in. x 4-in. lumber with studs spaced on 24-in. centers and 3/4-in. plywood floors. The ceiling, floor, and walls were double-covered with 6-mil polyethylene sheeting. (The interior layer of polyethylene sheeting was encapsulated and replaced after each experiment.) Where the joining of separate sheets of polyethylene was necessary, the sheets were overlapped at least 12 in. and joined with an unbroken line of adhesive to prohibit air movement. Three-inch-wide tape was then used to seal the joint further on both the inside and outside of the plastic sheeting.

Entry from one room to another was through a double-curtained doorway consisting of two overlapping sheets of 6-mil polyethylene placed over a framed doorway; each sheet was secured along the top of the doorway, and the vertical edge of one sheet was secured along one vertical side of the doorway and the vertical edge of the other sheet, along the opposite vertical side of the doorway.

Room size (approximately 29 ft x 17 ft x 7.5 ft) was determined based on the minimum amount of time required to vacuum or wet-clean the room and to attain an adequate volume of sample air to achieve a specified analytical sensitivity. A 52-inch, ceiling-mounted, axial-flow, propeller fan was installed in each room to facilitate air movement and to minimize temperature stratification.

Separate decontamination facilities for workers and waste materials were connected to the experimental areas. The worker decontamination facility consisted of three totally enclosed chambers as follows:

- 1) An equipment-change room with double curtained doorways, one to the work area and one to the shower room.
- 2) A shower room with double-curtained doorways, one to the equipment change room and one to the clean change room. The one shower installed in this room was constructed so that all water was collected and pumped through a three-stage filtration system. The

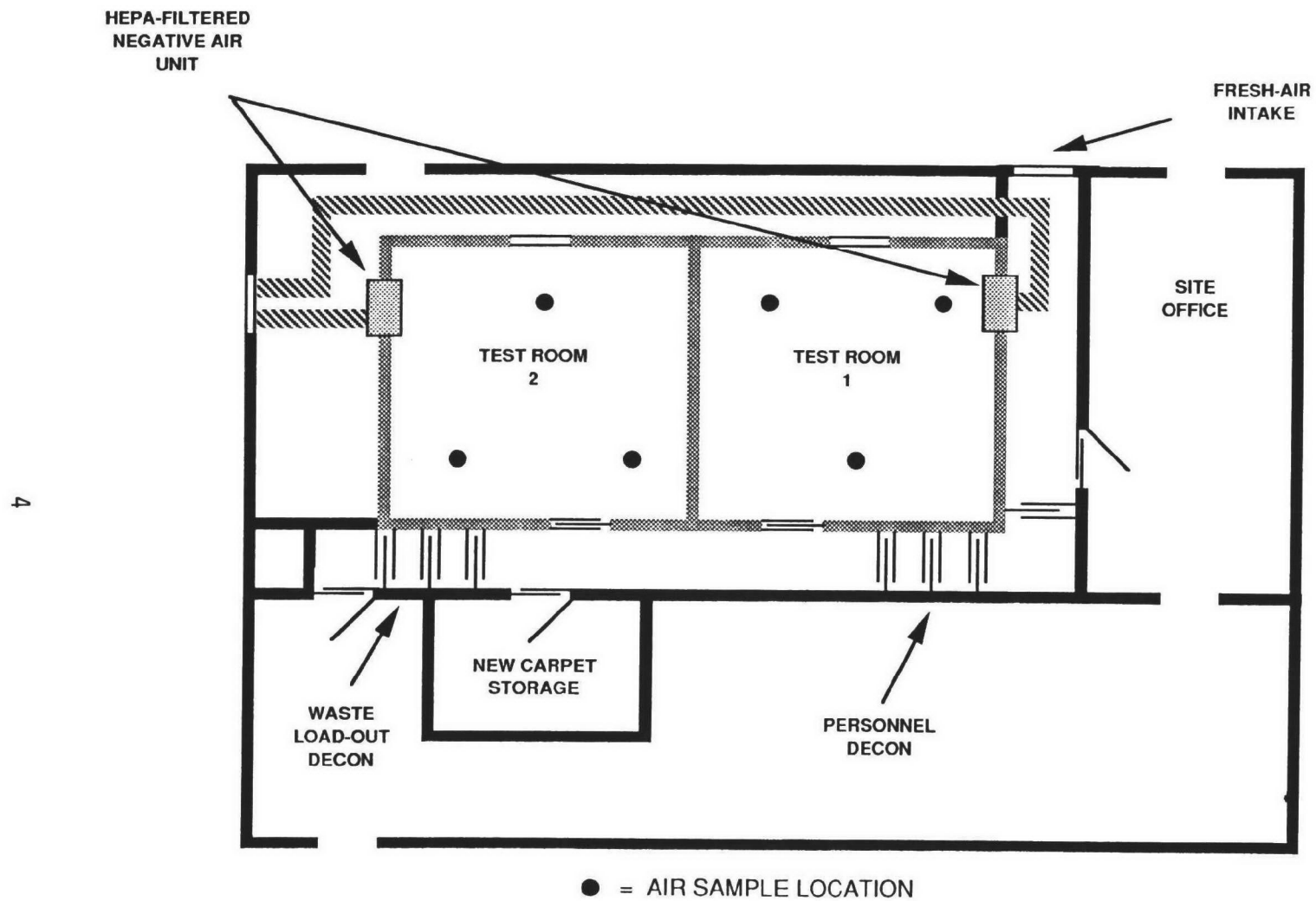


Figure 1. Layout of test facility.

three-stage filtration system consisted of a 400-micrometer, nylon-mesh, filter-bag prefilter; a 50-micrometer, filter-bag second-stage filter; and a 5-micrometer final-stage filter. Filtrate was disposed of as asbestos-contaminated waste. Water was drained from the filtration system exit into a sanitary sewerage system.

- 3) A clean change room with double-curtained doorways, one to the shower room and one to the noncontaminated areas of the building.

Air Filtration

High-efficiency particulate air filtration systems were used to reduce the airborne asbestos concentrations to background levels after each experiment. These units were operated during both preparation and decontamination of the test rooms. The air filtration units were not intended to be operated during the carpet cleaning phase of each experiment.

One HEPA filtration system was dedicated to each test room (Figure 1). Each unit provided approximately 8 air changes per every 15-minute period. The negative pressure inside the test rooms ranged from -0.08 to -0.06 in. of water. All exhaust air passed through a HEPA filter and was discharged to the outdoors (i.e., outside the building). All makeup air was obtained from outside the building through a window located on the opposite side of the building from the exhaust for the HEPA filtration systems.

EXPERIMENTAL DESIGN

Two carpet cleaning methods, dry vacuuming with a HEPA-filtered vacuum and wet cleaning with a HEPA-filtered hot-water extraction cleaner, were evaluated on carpet artificially contaminated with approximately 100 million and 1 billion asbestos structures per square foot (s/ft²). Each combination of cleaning method and contamination level was replicated four times. Four different (same model) HEPA-filtered vacuums and four different (same model) HEPA-filtered hot-water extraction units were used in this study so the results would not be influenced by the peculiarities of a single unit. Each machine was used only once per combination of cleaning method and contamination level. This experimental design, which yielded a total of 16 experiments, is summarized in Table 1.

TABLE 1. EXPERIMENTAL DESIGN

Approximate contamination level, s/ft ²	Cleaning method	
	Wet cleaning	Dry vacuuming
100 million	Experiments 1, 4, 5, 8	2, 3, 6, 7
1 billion	9, 12, 13, 16	10, 11, 14, 15

Two experiments were conducted each day of the study. Each combination of cleaning method and contamination level was tested twice in each test room. A single experiment consisted of contaminating a new piece of carpet (approximately 500 square feet) with asbestos fibers, collecting work-area air samples, dry vacuuming or wet cleaning the carpet while concurrently collecting a second set of work area air samples, removing the carpet, and decontaminating the test room. Each test room was decontaminated by encapsulating the polyethylene sheeting on the ceiling and walls and the carpet prior to their removal. These materials were replaced after each experiment.

SAMPLING STRATEGY

The number of samples collected was based, in part, on power calculations made during the design phase of the study. Statistical power is defined as the probability of detecting a difference between two sets of measurements (e.g., before and during cleaning) when a true difference actually exists. The probability of detecting a difference depends on the absolute magnitude of the airborne asbestos concentrations, their variability, and their statistical distribution. For planning purposes, it was assumed that individual airborne asbestos measurements would follow a negative binomial distribution with a coefficient of variation of approximately 100 percent. Table 2 shows the relationship between the number of samples and the probability of obtaining a statistically significant result at the 5 percent level, assuming a t-test will be used to compare two groups of measurements. Twelve samples per group are needed to detect a five-fold difference, with high probability (greater than 0.85).

TABLE 2. PROBABILITY OF DETECTING A STATISTICALLY SIGNIFICANT DIFFERENCE AT THE 5 PERCENT LEVEL OF SIGNIFICANCE BETWEEN TWO GROUPS OF AIRBORNE ASBESTOS MEASUREMENTS

Assumed airborne asbestos level for group 1 = 0.005 s/cm ³			
	Number of samples per group		
	4	8	12
Actual difference between groups			
Twofold	0.11	0.23	0.26
Fivefold	0.34	0.73	0.88
Tenfold	0.69	0.95	1.0
Assumed airborne asbestos level for group 1 = 0.02 s/cm ³			
	Number of samples per group		
	4	8	12
Actual difference between groups			
Twofold	0.21	0.25	0.39
Fivefold	0.45	0.76	0.91
Tenfold	0.78	0.97	1.0

The study was designed to achieve at least this power by having four replicates of each experiment and three samples per replicate. The actual power is expected to be greater than that indicated in Table 2 because the design permits comparisons involving more than two sets of measurements (i.e., analyses of variance rather than individual t-tests).

SECTION 4

MATERIALS AND METHODS

A survey was made of 14 General Service Administration (GSA) field offices in 11 States distributed across the United States to determine the most prevalent types of carpet, HEPA-filtered vacuum cleaner unit, and HEPA-filtered hot-water extraction unit to use in this study. Building managers were asked to identify 1) the specific type and manufacturer of carpet used in GSA buildings, 2) the manufacturer and model of HEPA-filtered vacuum cleaner commonly used, and 3) the manufacturer and model of HEPA-filtered hot-water extraction equipment routinely used in their buildings.

None of the GSA offices routinely wet-cleaned their carpet. When wet-cleaning was necessary, contractors were hired to perform the work. Therefore, six trade associations (the American Institute of Maintenance, the Building Service Contractors Association, the International Maintenance Institute, the Environmental Management Association, the International Sanitary Supply Association, and the Vacuum Cleaner Manufacturers Association) were surveyed to obtain their recommendations on a HEPA-filtered hot-water extraction cleaner.

SELECTION OF CARPET

Eight of the fourteen GSA offices indicated a preference for the same manufacturer and type of carpet. The selected carpet was first-grade, 100 percent nylon, with 0.25-inch cut pile, 28 ounces of yarn per square foot, and dual vinyl backing. The carpet was manufactured in roll sizes of 4.5 by 90 ft.

SELECTION OF CARPET CLEANING EQUIPMENT

HEPA-Filtered Vacuum

The HEPA-filtered vacuum selected for this study was the model most frequently mentioned in the GSA survey. The unit had an airflow capacity of 87 cubic feet per minute and a suction power of 200 watts. The standard filtration system consisted of a main cotton filter that permits a steady even airflow and has a high retention efficiency and an exhaust diffuser that insures a low exhaust velocity and additional air filtration. A HEPA exhaust filter was added to this standard filtration system to trap small particles and keep them from escaping into the air. The HEPA-filter had a retention

efficiency rating of 99.97 percent for particles larger than 0.3 micrometer. This unit was also equipped with a motor-driven carpet nozzle with a rotating brush.

Hot-Water Extraction Cleaner

Three of the trade associations surveyed recommended the same hot-water extraction unit. The selected cleaner was equipped with a HEPA-filtered power head and a moisture-proof, continuous-duty, 2-horsepower vacuum motor that develops a 100-inch waterlift. This unit was also equipped with an extractor tool that uses a motor-driven 4-inch-diameter by 14-inch-long cylindrical nylon-bristle brush to agitate and scrub the carpet during the extraction process.

SAMPLING METHODOLOGY

Air samples were collected on open-face, 25-mm-diameter, 0.45- μ m pore-size, mixed cellulose ester membrane filters with a 5- μ m pore-size, mixed cellulose ester backup diffusing filter and cellulose ester support pad contained in a three-piece cassette. The filter cassettes were positioned approximately 5 feet above the floor with the filter face at approximately a 45-degree angle toward the floor. The filter assembly was attached to an electric-powered vacuum pump operating at a flow rate of approximately 10 liters per minute. In each test room, the air samplers were positioned in a triangular pattern (Figure 1). Air samples were collected for a minimum of 65 minutes before and during carpet cleaning to achieve a minimum air volume of approximately 650 liters. The sampling pumps were calibrated both before and after sampling with a precision rotameter.

ANALYTICAL METHODOLOGY

The mixed cellulose ester filters were analyzed by transmission electron microscopy (TEM). These filters were prepared and analyzed in accordance with the nonmandatory TEM method as described in the Asbestos Hazard Emergency Response Act (AHERA) final rule (52 CFR 41821). Because no OSHA permissible exposure limits or NIOSH recommended exposure limits have been established for airborne asbestos measured by TEM, a subset of filters was selected for additional analysis by phase contrast microscopy (PCM) in accordance with NIOSH Method 7400. Battelle Laboratories, Columbus Division, performed the TEM and PCM analyses on the field samples under separate contract with EPA's Risk Reduction Engineering Laboratory (RREL) in Cincinnati, Ohio.

STATISTICAL ANALYSIS

Airborne asbestos concentrations were determined before and during carpet cleaning to study the effect of the cleaning method and contamination loading on fiber reentrainment during carpet cleaning. Three work-area samples were collected before and during the carpet cleaning for each experiment. A single estimate of the airborne asbestos concentrations before and

during cleaning was then determined by averaging the three respective work-area samples. As a measure of relative change in airborne asbestos concentration, the ratio of the concentration during cleaning to the concentration prior to cleaning was computed. The natural log of this ratio was then analyzed by using a two-factor analysis of variance (ANOVA)¹ with the cleaning method and contamination level as the main factors. The two-factor interaction term was also included in the model. This analysis is equivalent to assuming a lognormal distribution for airborne asbestos measurements and analyzing the log-transformed data for differences between airborne asbestos concentrations before and during cleaning. The lognormal distribution is commonly assumed for measurements of asbestos and other air pollutants. Summary statistics (arithmetic mean and standard deviation) were calculated according to cleaning method and contamination level.

SECTION 5

EXPERIMENTAL PROCEDURES

PRESTUDY AIR MONITORING

Before construction of the contamination enclosure system, air samples were collected to determine a baseline airborne asbestos concentration inside the test facility. Seven interior air samples and two field blanks were collected in accordance with sampling procedures described in Section 4. The air samples were collected for a period of approximately 200 minutes to achieve a minimum air volume of 1260 liters for each sample. These samples were analyzed in accordance with the nonmandatory TEM method as described in the AHERA Final Rule.

The average airborne asbestos concentration for the seven samples collected was 0.0031 s/cm³. The TEM analysis of the seven samples yielded a total of 6 asbestos structures (4 chrysotile and 2 amphibole). One chrysotile fiber was detected on each field blank. Table 3 summarizes these results.

TABLE 3. SUMMARY OF PRESTUDY AIRBORNE ASBESTOS
CONCENTRATIONS IN TEST FACILITY

Sample	Number of structures observed	Concentration, s/cm ³
001	1	0.0028
002	0	<0.0039
003	2	0.0077
004	0	<0.0038
005	1	0.0039
006	1	0.0039
007	1	0.0038
Field blank	1	-----
Field blank	1	-----

CARPET CONTAMINATION

Selected levels of carpet contamination for this study were based on field data reported by Wilmoth et al.² Asbestos concentrations in contaminated carpet ranging from approximately 8000 s/ft² to 2 billion s/ft² were detected by use of a microvac technique. Bulk sample sonication

of the samples revealed levels ranging from 30 million to 4 billion s/ft². Based on these preliminary results, the target experimental asbestos contamination levels of approximately 100 million and 1 billion s/ft² were thought to represent carpet contamination likely to be present in buildings where asbestos-containing materials are present.

The carpet was contaminated with a spray-applied dispersion of Union International Centre le Centre Calidria chrysotile asbestos in distilled water. The asbestos was dispersed uniformly on the carpet by use of a manual pesticide sprayer equipped with a stainless steel container.

Preparation of Concentrated Aqueous Suspensions of Chrysotile

Aqueous suspensions of chrysotile are not stable for long periods unless they are specially prepared.³ Even small amounts of high-molecular-weight organic materials, such as those generated by bacteria, result in the destabilization of chrysotile suspensions and the attachment of fibers to the walls of the container. This process can be reversed only by carrying out oxidation of the organic materials with ozone and ultraviolet light treatment.³ If precautions are taken to exclude all organic materials and to prevent bacterial growth, however, chrysotile suspensions can be prepared that remain stable for several years. This can be achieved by sterilizing all containers used in the preparation, using freshly distilled water for the dispersion process and storing the preparation in flame-sealed glass ampules that are autoclaved immediately after sealing.

For this project, the decision was made to prepare sealed ampules of fiber dispersions so that the contents of one ampule dispersed in 6 liters of freshly distilled water would provide the concentration of suspension required for artificial contamination of one 500-ft² sample of carpet. Calculations of the amount of chrysotile required were based on the assumption that all of the fibers needed to contaminate one carpet sample would be contained in a volume of 50 ml sealed in one ampule.

For the higher of the two concentrations used, the fiber concentration required in each ampule was calculated as follows:

Higher contamination level required	= 10 ⁹ fibers/ft ²
Number of fibers required to contaminate 500 ft ²	= 6.5 x 10 ¹¹ fibers
Fiber concentration required for this number of fibers to be in a volume of 50 ml	= 1.3 x 10 ¹³ fibers/liter

The lower of the two concentrations used was a factor of 10 lower than this. To ensure an exact factor of 10 ratio between the two concentrations, the lower-concentration dispersion was prepared by diluting an aliquot of the high-concentration dispersion.

Because the original suspension was to be prepared by dispersing a known weight of chrysotile in water, knowledge of what numerical concentration of

fibers would result from this dispersion was required. Previous work on preparation of ampules indicated that a suspension of purified Calidria chrysotile in water, with a mass concentration of 1 $\mu\text{g/liter}$ yielded a numerical fiber concentration of approximately 200 million fibers per liter. Based on this conversion, the weight of chrysotile is calculated as follows:

$$\begin{aligned}\text{Weight required} &= 1.3 \times 10^{13} \times 10^{-6} / (2 \times 10^8) \text{ g/liter} \\ &= 65 \text{ mg/liter}\end{aligned}$$

Therefore, the preparation of 1.5 liters of a suspension with this concentration requires 97.5 mg of chrysotile.

The calculation for determining the mass of chrysotile required is based on data from very dilute suspensions. Initial experiments indicated that some difficulty could arise in obtaining complete dispersal of the chrysotile at the high concentrations in this program; if some aggregation were to occur, the numerical structure count would be somewhat lower than that required. For this reason, the suspensions were prepared to have a higher mass concentration than that indicated in the preceding calculation.

Before preparation of the fiber suspensions, the 50-ml ampules were thoroughly cleaned. Each ampule was filled to the top with freshly distilled water and placed in an ultrasonic bath for a period of 15 minutes; the water was then removed by suction. This process was repeated twice, and the ampules were then considered ready for filling.

The higher-concentration chrysotile suspension was prepared first. All water used for preparation of these dispersions was freshly distilled (within 8 hours of preparation). A weight of 409.5 mg of purified Calidria chrysotile was placed in an agate mortar and lightly ground with a small volume of water by use of a pestle. More freshly distilled water was added gradually until a creamy liquid was obtained. Up to 400 mL of this liquid was made up in a disposable polypropylene beaker, and the beaker was placed in an ultrasonic bath for approximately 30 minutes. Up to 1500 ml of the chrysotile suspension was then made up with water in a 1-gallon polyethylene bottle. The bottle was placed in an ultrasonic bath for approximately 30 minutes. During this time, the bottle was removed several times and shaken vigorously. For the lower-concentration suspension, a volume of 150 ml, up to 1500 ml of this suspension was made up with water in another 1-gallon polyethylene bottle. The two suspensions had concentrations of 273 and 27.3 mg/liter, respectively.

A disposable polyethylene funnel was used to place a volume of 50 mL of suspension in each of the ampules. This left adequate space in the ampule to permit efficient shaking of the contents. The filled ampules were flame-sealed immediately and then autoclaved for 30 minutes at a temperature of 121°C to sterilize the contents. After the ampules cooled, they were labeled in the order of their filling.

Preparation of Asbestos Dispersion

The following steps were followed precisely in the preparation of the asbestos dispersions used to contaminate the carpet:

1. All water used for dilution of the ampules of chrysotile suspension was freshly distilled from a glass still.
2. Before the ampule was opened, it was shaken vigorously for 1 minute and then placed in an ultrasonic bath for 30 minutes. During the ultrasonic treatment, the ampule was removed every 5 minutes and again shaken vigorously for 1 minute.
3. A new 32-ounce glass bottle was washed with several changes of freshly distilled water. The ampule was then opened, and the entire contents were emptied into 450 ml of freshly distilled water in the glass bottle. For the high-concentration ampules only, the pH was adjusted to approximately 4.0 by adding approximately 300 to 400 μ l of glacial acetic acid. The bottle was capped, shaken vigorously, and then placed in an ultrasonic bath for 15 minutes. No surface active agents were added.
4. The pesticide sprayer was sterilized and cleaned by rinsing it with a 10 to 15 percent solution of Clorox for approximately 15 minutes. The sprayer, including the interior of the outlet pipe, was then thoroughly washed with several changes of freshly distilled water.
5. The sprayer was filled with 5.5 liters of freshly distilled water, and the contents of the bottle were added. The sprayer was then shaken before the carpet was sprayed.

The sprayer was not allowed to dry before it was washed after each experiment because chrysotile is much more difficult to remove from the interior surfaces when it has dried.

To ensure no bacterial growth had occurred in the sprayer between uses, the inside of the sprayer and the outlet pipe were treated with a 10 to 15 percent solution of Clorox to remove any bacteria and their byproducts. Any bacterial growth would scavenge fibers from the suspension and cause fibers to become attached to the wall of the container. The container and outlet pipe were then rinsed with isopropyl alcohol.

Concentrations of Suspensions

Several of the ampules were used to make precise measurements of the fiber concentrations and also to determine the fiber size distributions. In order to measure these very high fiber concentrations, a total dilution factor of 1 in 25,000 was necessary for the low-concentration ampules, and 1 in 250,000 for the high-concentration ampules. This was achieved by successive dilutions in freshly distilled water. For the low-concentration ampules, the contents of one ampule were first dispersed in 500 ml. In the second dilution, 10 ml were diluted to 500 ml, and 10 ml of the second dilution were

diluted to 500 ml. Three filters were prepared from this final suspension, using the EPA Analytical Method for Determination of Asbestos Fibers in Water. For the high-concentration ampules, the final suspension was diluted by a further factor of 10 before preparation of the filters.

The dilution factors and the volumes of suspension filtered were selected to yield fiber counts of approximately 40 per grid opening. One fiber count incorporating approximately 600 asbestos structures was made for each of the two concentrations.

It was found that the high-concentration ampules yielded asbestos structure counts which were significantly lower than those obtained during the initial tests on the suspension at the time the ampules were prepared. This effect was investigated, and found to be a consequence of a rise in pH of the suspension after packing and autoclaving. The increase in the pH was probably due to some leaching of the chrysotile during the autoclave treatment, giving rise to destabilization of the dispersion, and aggregation of the fibers into bundles and clusters. The effect was found to be reversible by adjusting the pH of the dispersion to approximately 4.0 with acetic acid at the time of the first dilution. The measurements on the high-concentration ampules were repeated using another ampule and adjusting the pH during preparation of the first dilution. The aggregation effect did not occur in the low-concentration ampules, and therefore no pH adjustment was required when these ampules were used.

Table 4 shows the results of the fiber concentration measurements made on the low- and high-concentration ampules. The analysis of the laboratory dilution was continued for approximately 600 chrysotile structures to provide a precise concentration value and to provide a size distribution with a sufficient number of structures in each size classification. Appendix A contains the size distributions for the measurements made on the low- and high-concentration ampules. Figure 2 illustrates the fiber size distribution in the low- and high-concentration ampules.

TABLE 4. SUMMARY OF RESULTS OF TRANSMISSION ELECTRON MICROSCOPY ANALYSES FOR LOW AND HIGH CONCENTRATION AMPULES

Sample description	Fiber type	Structure concentration, 10^{12} structures/liter			Equivalent volume sampled, μ l	No. of structures counted
		Mean	95% confidence interval	Analytical sensitivity		
Low-concentration ampule	Chrysotile	2.2	2.0-2.5	0.0036	0.400	619
High-concentration ampule	Chrysotile	25	22-27	0.0409	0.040	601

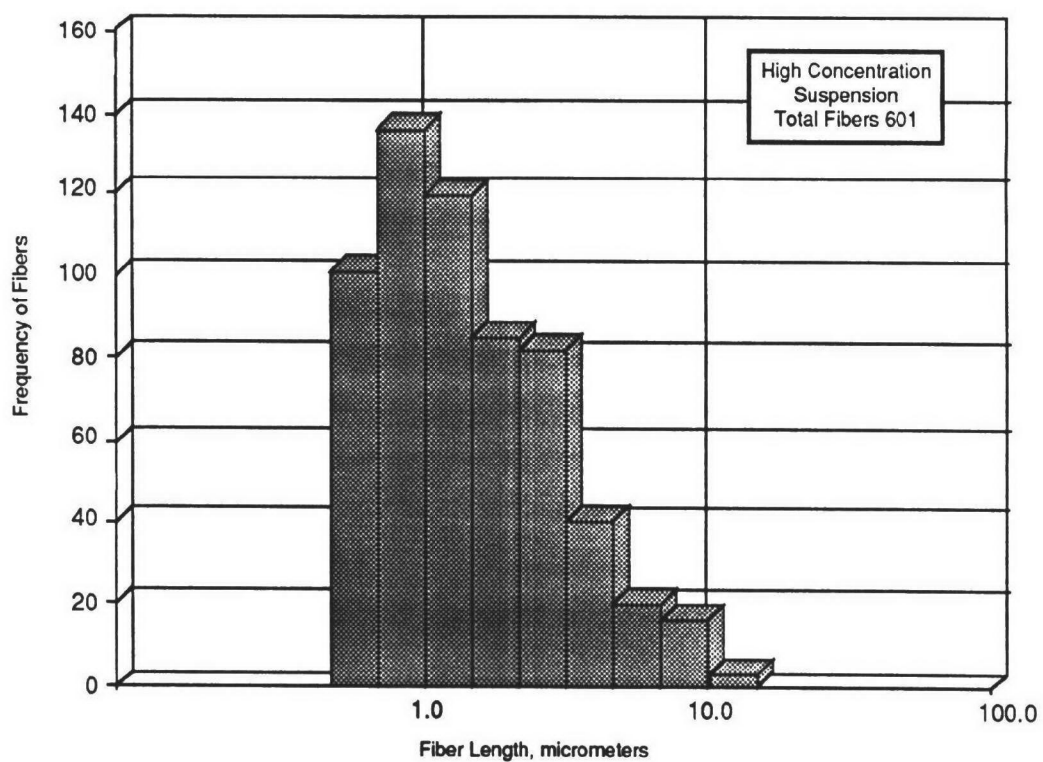
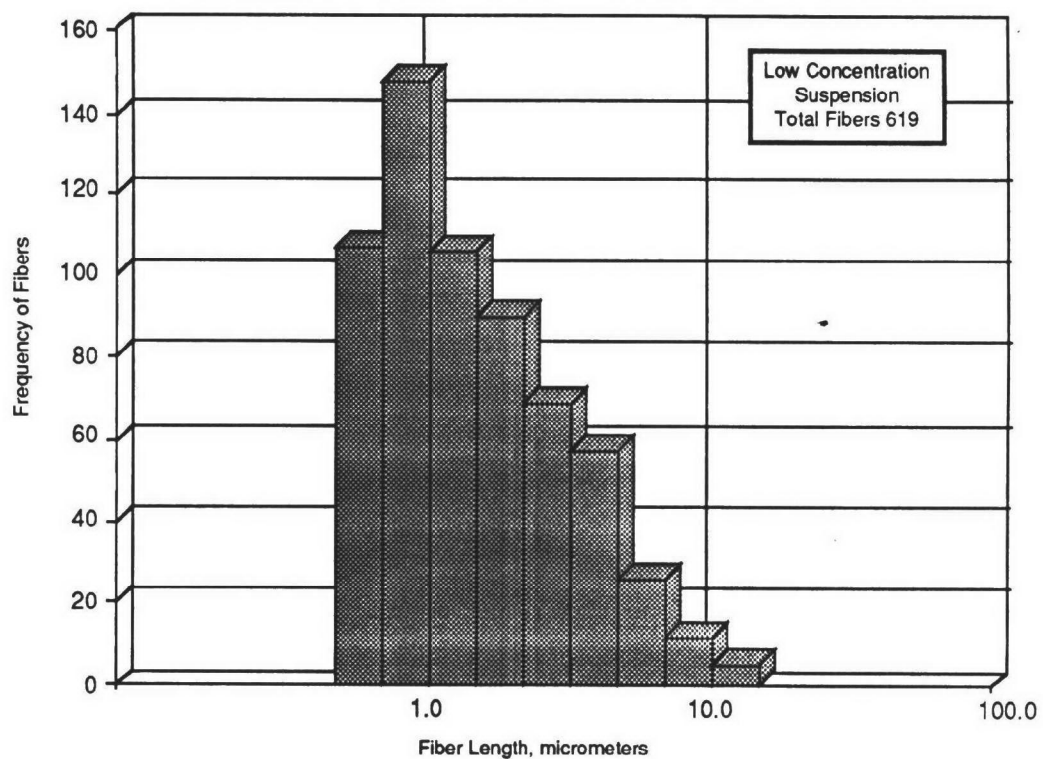


Figure 2. Distribution of chrysotile fiber lengths in the low and high concentration aqueous asbestos suspensions.

Application of Dispersion to Carpet

A meticulously cleaned hand-pumped garden sprayer was used to apply the asbestos dispersion to the carpet. A fixed number of pumps was used for each batch to provide consistent spray pressure. The desired controlled spray was experimentally determined by trial and error before the tests with asbestos began. The pressure was kept within the desired range by adding a fixed number of pump strokes after each fixed area was sprayed in a predetermined pattern by following a grid work of string placed over the carpet before the beginning of each experiment. The tank was periodically agitated to help keep the asbestos fibers suspended. Dehumidifiers were placed in the room overnight to aid in drying the carpet. The following day a 200-pound steel lawn roller was rolled over the carpet surfaces to simulate the effects of normal foot traffic in working the asbestos into the carpet.

Carpet Cleaning Technique

The carpet was vacuumed or wet-cleaned for a period of approximately 65 minutes to allow the collection of a sufficient volume of air samples to obtain an analytical sensitivity of 0.005 s/cm^3 of air. The carpet was cleaned in two directions, the second direction at a 90-degree angle to the first.

DISPOSAL OF ASBESTOS-CONTAINING MATERIAL

Asbestos-contaminated materials, including carpeting, polyethylene, protective clothing, etc., were placed in disposable 6-mil polyethylene bags and labeled according to EPA regulations. When filled, the disposal bags were sealed, sponged clean, and removed from the test room to the primary waste-loadout work area (Figure 1). The disposal bag was then sponged a second time, taken through the equipment-change area, and placed in the shower chamber for a thorough washing. The clean disposal bag was taken into the clean chamber, loaded into a fiberboard drum, labeled with an EPA-approved asbestos warning label, and transported to a disposal site approved by the Ohio Environmental Protection Agency.

SITE CLEANUP

Prior to removal of the primary polyethylene barrier (i.e., the first barrier installed to isolate the work area, including test rooms), the surface was thoroughly wet-wiped with amended water. The HEPA filtration system continued to operate during site cleanup.

All debris and waste resulting from the experiments were removed from the building. All the drummed waste was removed from the site and disposed of in an Ohio EPA-approved landfill.

POSTSTUDY AIR MONITORING

After removal of the polyethylene sheeting from the floor, ceiling, and walls, air samples were collected to determine the airborne asbestos concentrations inside the building. Four interior air samples were collected in accordance with the sampling procedures described in Section 5. These samples were collected for a period of approximately 180 minutes to achieve a minimum air volume of approximately 1800 liters for each sample. These samples were analyzed in accordance with the nonmandatory TEM method as described in the AHERA Final Rule. No asbestos was detected in any of these samples.

SECTION 6

QUALITY ASSURANCE

The Quality Assurance Project Plan (QAPP) contains complete details of the quality assurance procedures followed during this research project. The procedures used for this study are summarized in the following subsections.

SAMPLE CHAIN OF CUSTODY

Sample chain-of-custody procedures were an integral part of both sampling and analytical activities during this study. They were followed for all air samples collected. The applied field custody procedures documented each sample from the time of its collection until its receipt by the analytical laboratory. Internal laboratory records then documented the custody of the sample through its final disposition.

Standard sample custody (traceability) procedures were used. Each sample was labeled with a unique project identification number, which was recorded in the field log book along with other information specified by the QAPP.

QUALITY ASSURANCE SAMPLE ANALYSES

Specific quality assurance procedures for ensuring the accuracy and precision of the TEM analyses of air samples included the use of lot, laboratory, and field blanks and replicate and duplicate analyses.

Lot Blanks

Filter lot blanks consist of unused filters selected at random and submitted for prescreening analysis for background asbestos contamination before the start of field work to determine the integrity of the entire lot of filters purchased for EPA research studies. One hundred lot blanks were submitted for TEM analysis. No asbestos structures were detected in the 1000 grid openings analyzed. The lot of filters was subsequently considered acceptable for use.

Field and Laboratory Blanks

During the setup of the air sampling pumps, preloaded filter cassettes were labeled and handled in a manner similar to that for the actual sample filters, but they were never attached to the pump. One field blank was

collected for each of the 16 experiments. Two of the 16 filters each contained 1 asbestos structure. Also, prior to each of the 16 experiments, one sample cassette was selected from the filter inventory to be used as a laboratory blank. These samples were sealed and submitted for use by the analytical laboratory to ensure against any blank interference during the analytical procedures. Two of the 16 sealed blanks each contained 2 asbestos structures. Analysis of the field and laboratory blanks demonstrated that filter contamination was comparable to background levels of asbestos air filters (defined as 70 s/mm² in AHERA). Table 5 summarizes the results of the field and laboratory blanks.

TABLE 5. SUMMARY OF FIELD AND LABORATORY BLANK ANALYSES

Experiment	Asbestos concentration, s/mm ²	
	Field blank	Laboratory blank
1	<14	<14
2	14	<14
3	14	28
4	<14	<14
5	<14	28
6	<14	<14
7	<14	<14
8	<14	<14
9	<14	<14
10	<14	<14
11	<14	<14
12	<14	<14
13	<14	<14
14	<14	<14
15	<14	<14
16	<14	<14

Duplicate and Replicate Sample Analyses

Duplicate sample analysis provides a means of quantifying intralaboratory precision and refers to the analysis of the same grid preparation by a second microscopist. Five samples were randomly selected for duplicate analysis. Replicate sample analysis provides a means of quantifying any analytical variability introduced by the filter preparation procedure and refers to the analysis of a second grid preparation from the original filter. Five samples were randomly selected for replicate analysis.

The coefficient of variations for the duplicate and replicate analyses were estimated by assuming a lognormal distribution for the data on the original scale and estimating the variance on the log scale. The variance was estimated by the mean square error obtained from a one-way ANOVA of the log-transformed data with sample ID as the experimental factor. The coefficient of variations associated with the duplicate and replicate sample

analyses were 22 and 32 percent, respectively. Since the replicate analyses used different filter preparations, a higher coefficient of variation is not unexpected. Table 6 presents the results of the duplicate and replicate analyses.

TABLE 6. RESULTS OF REPLICATE AND DUPLICATE SAMPLE ANALYSES

Sample	Original		Duplicate		Replicate	
	N	s/cm ³	N	s/cm ³	N	s/cm ³
01-A444B	47	0.1810	33	0.1271	-	-
04-A464D	37	0.1242	39	0.1309	-	-
07-A482D	57	0.2758	53	0.2565	-	-
14-A525D	53	0.3368	50	0.2174	-	-
16-A533B	8	0.0306	12	0.0459	-	-
02-A451D	2	0.0070	-	-	2	0.0070
05-A467B	6	0.0220	-	-	4	0.0147
10-A500D	51	0.4891	-	-	51	0.3113
13-A516B	19	0.0719	-	-	10	0.0378
15-A529D	41	0.1482	-	-	26	0.0940

SPRAY-APPLICATION TECHNIQUE

To confirm the validity of the spraying technique, an additional experiment was conducted using a pesticide sprayer identical to those used to apply the chrysotile to the carpet samples. An ampule of low-concentration suspension was diluted to 500 ml, and then further diluted to 6 liters in the pesticide sprayer, using freshly distilled water. The sprayer was thoroughly shaken, and the contents were sprayed out into several containers. Three 500-ml samples of the spray were collected, one at the beginning of spraying, one when approximately 50 percent of the contents had been discharged, and one just before the end of spraying. These three samples were analyzed to determine if the concentration and size distribution of the fibers changed during the period of spraying. Structure concentrations for the three samples are presented in Table 7. These results indicate no significant loss of fibers during the transfer of the diluted liquid suspension through the sprayer's hose and nozzle.

The size distributions for these three samples are shown in Table 8 and illustrated in Figure 3. Since the distributions all approximate logarithmic-normal, the size range intervals for calculation of the distribution must be spaced logarithmically. Another characteristic required for the choice of size intervals is that they allow for a sufficient number of size classes, while still retaining a statistically-valid number of fibers in each class. Interpretation is also facilitated if each size class repeats at decade

TABLE 7. RESULTS FROM PRELIMINARY STUDY OF ASBESTOS DISPERSION BY SPRAYING--FIBERS AND FIBER BUNDLES

Volume in sprayer at time of sample collection, liters	Fiber type	Structure concentration, 10 ¹² structures/liter			Number of structures counted
		Mean	95% con- fidence interval	Analytical sensitivity	
6 (Beginning of spray)	Chrysotile	2.33	1.87-2.79	0.0118	198
4 (50% point of spray)	Chrysotile	2.18	1.54-2.82	0.0118	185
2 (End of spray)	Chrysotile	2.38	1.90-2.85	0.0118	202

TABLE 8. FIBER LENGTH DISTRIBUTIONS FROM THE PRELIMINARY STUDY OF ASBESTOS DISPERSION BY SPRAYING

Particle size range, μm	Number of fibers, fiber bundles (cumulative percentage)		
	Beginning of spray	50% point of spray	End of spray
0.23-0.34	0 (0)	0 (0)	0 (0)
0.34-0.50	0 (0)	0 (0)	0 (0)
0.50-0.73	28 (14.14)	33 (17.84)	24 (11.88)
0.73-1.08	48 (38.38)	55 (47.57)	43 (33.17)
1.08-1.58	34 (55.56)	28 (62.70)	45 (55.45)
1.58-2.32	30 (70.71)	20 (73.51)	28 (69.31)
2.32-3.41	34 (87.88)	17 (82.70)	22 (80.20)
3.41-5.00	18 (96.97)	14 (90.27)	19 (89.60)
5.00-7.34	4 (98.99)	10 (95.68)	13 (96.04)
7.34-10.77	1 (99.49)	5 (98.38)	5 (98.51)
10.77-15.81	1 (100.00)	3 (100.00)	1 (99.01)
15.81-23.21	0 (100.00)	0 (100.00)	1 (99.50)
23.21-34.06	0 (100.00)	0 (100.00)	0 (99.50)
34.06-50.00	0 (100.00)	0 (100.00)	1 (100.00)

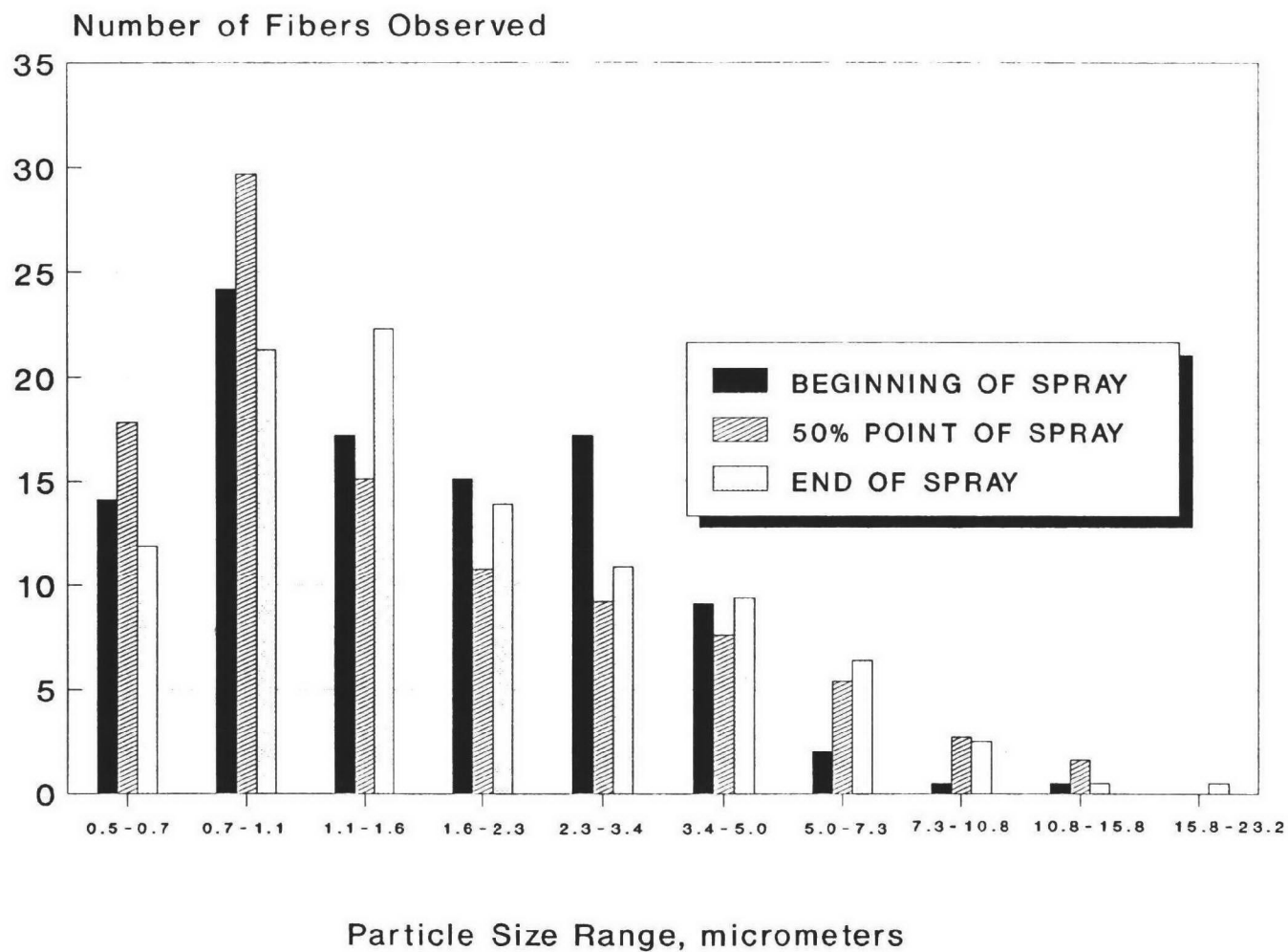


Figure 3. Fiber size distributions from preliminary study of asbestos dispersion by spraying.

intervals. A ratio of 1.468 from one class to the next satisfies all of these requirements. The other constraint is that the length distribution should include the minimum fiber length of 0.5 μm at the first interval point. The decade repeat automatically ensures that the other significant fiber length of 5 μm occurs as an interval point.

No significant change in the fiber size distribution was evident during the transfer of the diluted liquid suspension.

SECTION 7

RESULTS AND DISCUSSION

Figure 4 presents the average airborne asbestos concentrations measured before and during cleaning for each cleaning method and carpet contamination loading. The samples collected before cleaning were obtained after the carpet was contaminated to determine the baseline concentration in the test room. Table 9 presents the summary statistics (arithmetic average and standard deviation). Individual air sampling results analyzed by TEM are listed in Appendix B.

Air sampling results from 2 of the 16 experiments showed that the average airborne asbestos concentrations decreased during both wet cleaning and dry vacuuming of the carpet. The explanation for this anomaly is that the HEPA filtration system used to ventilate the test rooms was inadvertently operating during the carpet cleaning phase of these two experiments. Therefore, these results were omitted from the statistical analysis of the data.

Results from the two-factor ANOVA are summarized in Table 10. There was no statistically significant interaction between cleaning method and contamination level ($p = 0.8901$). That is, the effect of cleaning method on airborne asbestos did not vary significantly with contamination level. No statistically significant difference was evident between cleaning methods with respect to fiber reentrainment ($p = 0.5847$); that is, the mean relative increase in airborne asbestos concentration during carpet cleaning with a dry vacuum was not significantly different from that found during wet cleaning. Similarly, no statistically significant difference was evident between carpet contamination loadings with respect to fiber reentrainment ($p = 0.0857$); that is, the mean relative increase in airborne asbestos concentrations during carpet cleaning when the carpet contamination level was 100 million s/ft² was not significantly different from that found when the carpet contamination loading was 1 billion s/ft². The ANOVA results do, however, indicate that, overall, the mean airborne asbestos concentration was significantly higher during carpet cleaning than just prior to cleaning ($p = 0.0001$). Specifically, a 95 percent confidence interval for the mean airborne asbestos concentration during carpet cleaning as a proportion of the airborne concentration before cleaning showed that the mean airborne asbestos concentration was between two and four times greater during carpet cleaning.

Airborne Asbestos Fiber Distribution

The TEM analysis of the 95 work-area samples before and during cleaning yielded a total of 2839 structures. Of these, 2757 (97.1%) were chrysotile,

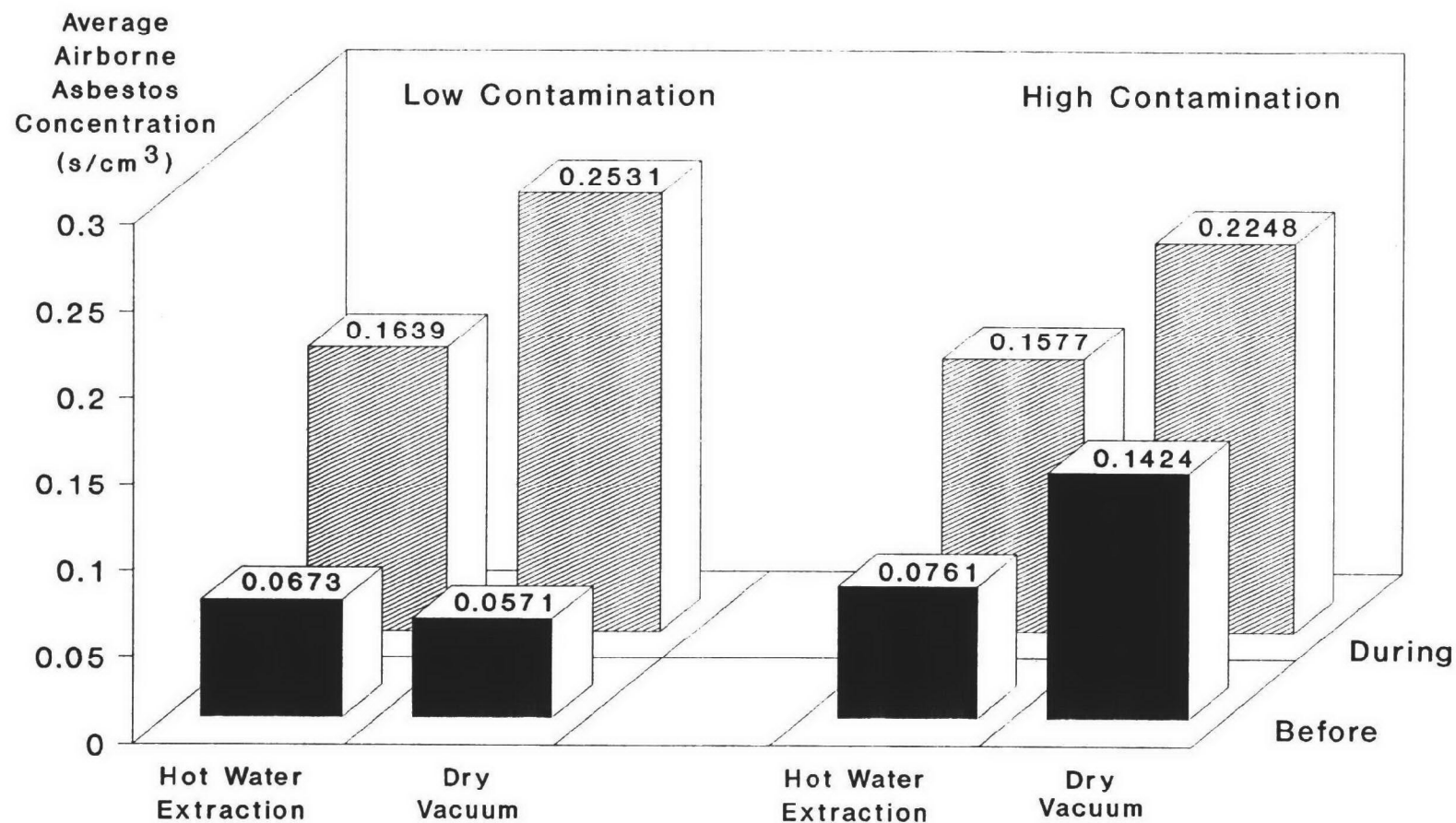


Figure 4. Average airborne asbestos concentrations before and during carpet cleaning.

TABLE 9. SUMMARY STATISTICS FOR AIRBORNE ASBESTOS CONCENTRATIONS
BEFORE AND DURING CARPET CLEANING

Approximate contamination loading, s/ft ²	HEPA- filtered cleaner	Number of data points ^a	Airborne asbestos concentration, s/cm ³	
			Average	Standard deviation
100 million		Before cleaning		
	Hot-water extraction	3	0.0673	0.0874
	Dry-vacuum	3	0.0571	0.0315
		During cleaning		
	Hot-water extraction	3	0.1639	0.0911
	Dry-vacuum	3	0.2531	0.1655
1 billion		Before cleaning		
	Hot-water extraction	4	0.0761	0.0471
	Dry-vacuum	4	0.1424	0.1235
		During cleaning		
	Hot-water extraction	4	0.1577	0.0690
	Dry-vacuum	4	0.2248	0.1499

^a Each data point is the average of three work-area samples.

TABLE 10. SUMMARY OF ANOVA RESULTS FOR AIRBORNE ASBESTOS CONCENTRATIONS
MEASURED BEFORE AND DURING CARPET CLEANING

Source of variation	Degrees of freedom	Sum of squares	F value	P value
Contamination level	1	1.5326	3.63	0.0857
Cleaning method	1	0.1345	0.32	0.5847
Interaction	1	0.0085	0.02	0.8901
Average	1	15.5827	36.94	0.0001
Error	10	4.2179		

8 (0.03%) were amphibole, and 74 (2.6%) were ambiguous. The structure morphology distribution is summarized in Table 11.

TABLE 11. STRUCTURE MORPHOLOGY DISTRIBUTION FOR AIR SAMPLES COLLECTED BEFORE AND DURING CARPET CLEANING

Structure type	Number of bundles	Number of clusters	Number of fibers	Number of matrices	Total
Chrysotile	30	7	2661	59	2757
Amphibole	0	2	5	1	8
Ambiguous	2	0	70	2	74
Total	32	9	2736	62	2839

These data indicate that the original chrysotile fibers used to prepare the diluted asbestos suspension remained intact as fibers. There appeared to be no significant tendency for the fibers to clump together as a result of the suspension preparation, the carpet contamination, or the cleaning technique.

The presence of amphibole asbestos fibers in the air was probably due to conditions existing prior to the experiment. Prestudy air monitoring identified two amphibole asbestos fibers in seven air samples collected.

Appendix C presents the structure-length distributions of asbestos particles found in the air before and during carpet cleaning. Eighty-four percent of the chrysotile structures identified were 1 micrometer or less in length. Only nine particles were identified with lengths greater than 5 micrometers. Figure 5 compares the fiber sizes of airborne asbestos during carpet cleaning with fibers in the low- and high-concentration asbestos suspensions. For example, approximately 60 percent of the asbestos fibers used to contaminate the carpet with 100 million s/ft² were greater than 1.1 μm . Less than 15 percent of the fiber observed in the air during carpet cleaning were greater than 1.1 μm . These data suggest that the larger asbestos particles either remained in the carpet or were prevented from escaping into the air by the carpet cleaning activity.

Figure 6 presents average airborne asbestos concentrations based on particles greater than or equal to a given length. These "cumulative" concentrations illustrate that for both dry vacuuming and wet cleaning, the overall airborne asbestos concentrations observed in this study were based primarily on asbestos structures less than 1.5 μm in length.

Samples Analyzed by PCM

Twelve samples were selected to be analyzed by phase contrast microscopy (PCM) based on their respective high asbestos concentrations determined by

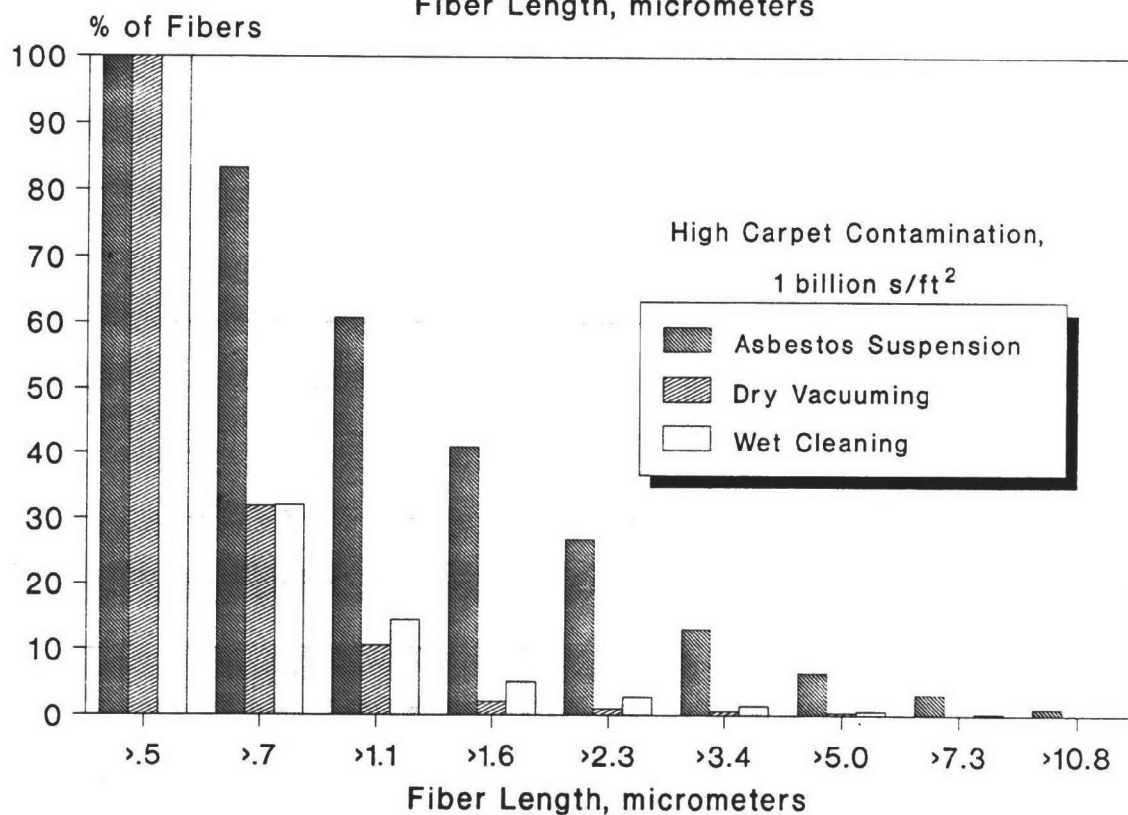
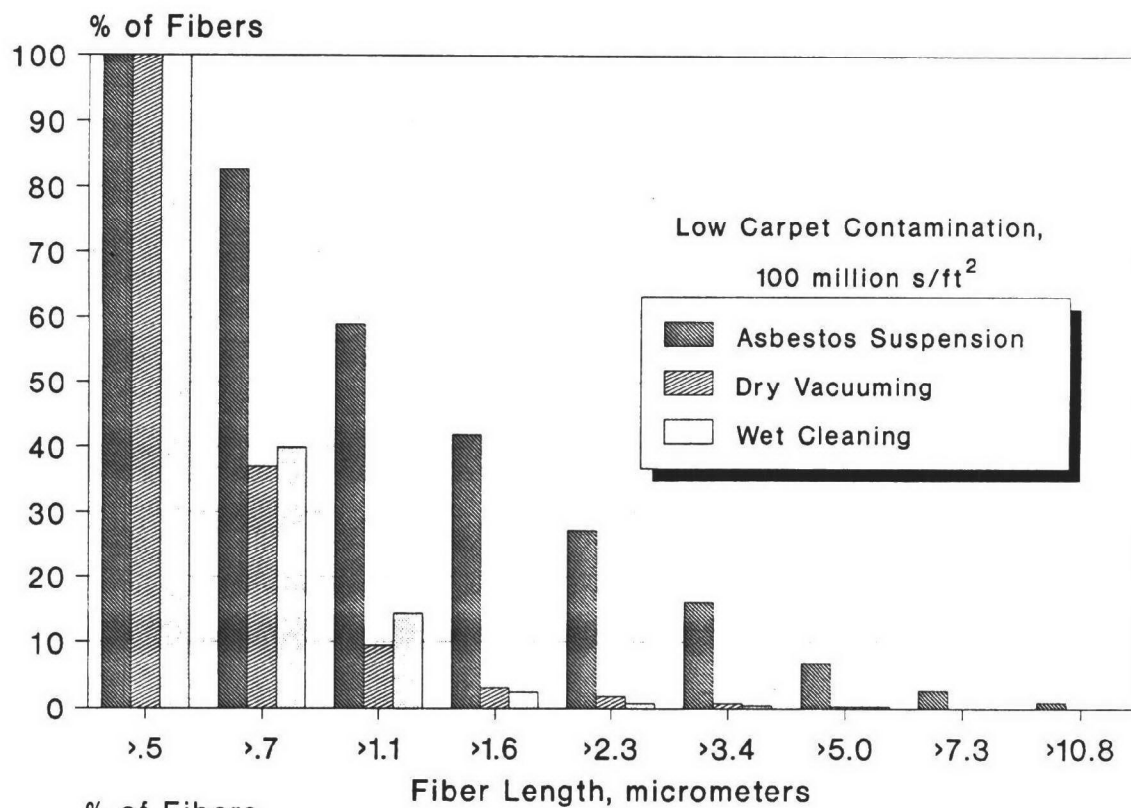


Figure 5. Comparative plot of cumulative percentages of airborne asbestos fibers during dry vacuuming and wet cleaning of carpet with asbestos fibers in the low and high concentration suspensions.

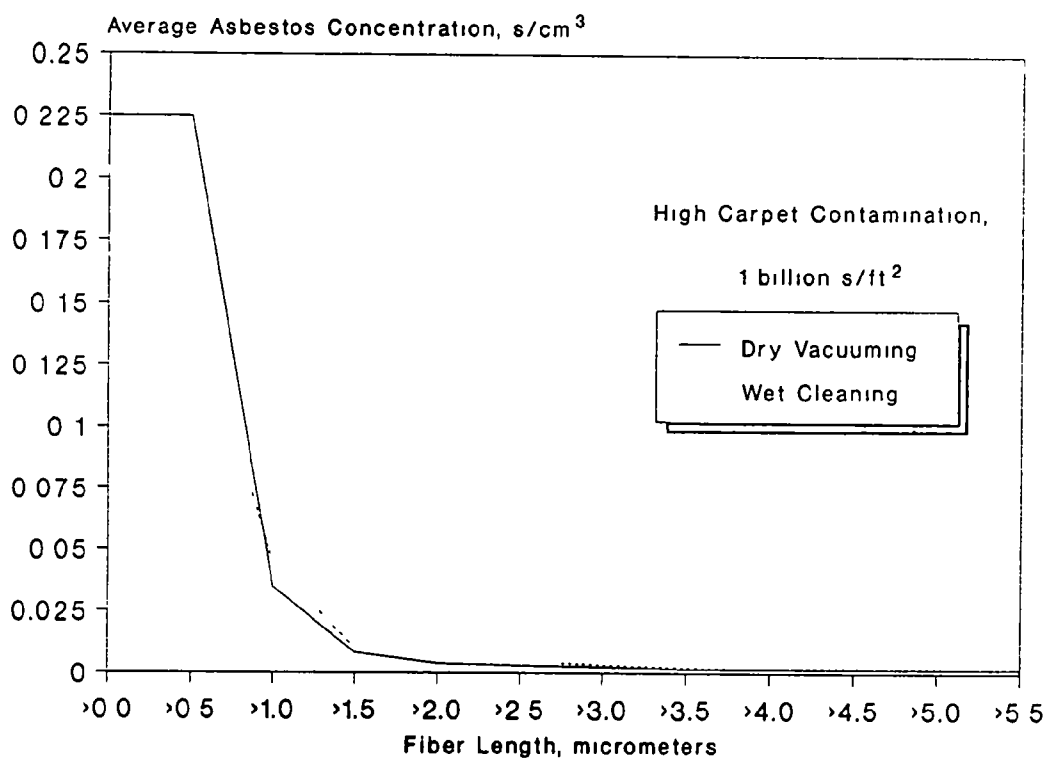
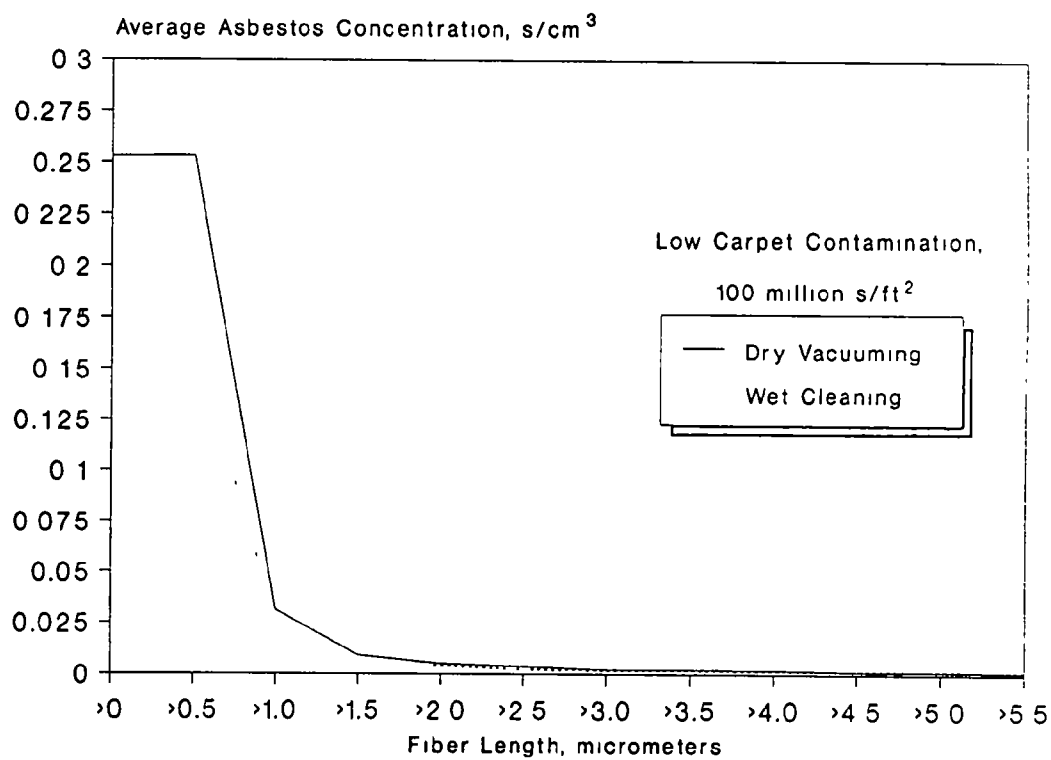


Figure 6. Airborne asbestos concentrations for varying fiber lengths for samples collected during dry vacuuming and wet cleaning of carpet.

TEM. Results from both TEM and PCM analyses are compared in Table 12. As expected, airborne fiber concentrations determined by PCM were significantly lower than the corresponding asbestos concentrations determined by TEM. This difference is presumably due to the limitation of PCM to detect small fibers. Furthermore, the majority of asbestos fibers applied (Figure 2) did not meet the dimensional criteria (length $>5 \mu\text{m}$) of NIOSH Method 7400 and hence were not counted.

TABLE 12. COMPARISON OF TEM AND PCM ANALYSES OF SELECTED AIR SAMPLES

Sample number	PCM fiber concentration, f/cm^3	TEM asbestos concentration, s/cm^3
03-A457D	0.0035	0.5507
03-A458D	0.0023	0.3658
03-A459D	0.0081	0.3464
10-A496B	0.0026	0.3656
10-A497B	0.0078	0.2909
10-A498B	0.0068	0.3375
10-A499D	0.0116	0.3871
10-A500D	0.0109	0.4891
10-A501D	0.0000	0.0070
14-A523D	0.0061	0.3177
14-A524D	0.0138	0.3779
14-A525D	0.0138	0.3368

REFERENCES

1. Neter, J., W. Wasserman, and M. H. Kutner. Applied Linear Statistical Models. 2nd Ed. Richard D. Irwin, Inc., Homewood, Illinois. 1985.
2. Wilmoth, R., T. J. Powers, and J. R. Millette. Observations in Studies Useful to Asbestos O&M Activities. Presented at the National Asbestos Council Conference in Atlanta, Georgia, February 1988.
3. Chatfield, E. J., and M. J. Dillon. Analytical Method for Determination of Asbestos Fibers in Water. PB 83-260-471. U.S. Environmental Research Laboratory, Athens, Georgia. Contract 68-03-2717. National Technical Information Service, Springfield, Virginia. 1983.
4. Chatfield, E. J., M. J. Dillon, and W. R. Stott. Development of Improved Analytical Techniques for Determination of Asbestos in Water Samples. PB 83-261-471. U.S. Environmental Research Laboratory, Athens, Georgia. 1983.

APPENDIX A

CHRYSOTILE FIBER SIZE DISTRIBUTION IN THE HIGH- AND LOW-CONCENTRATION AMPULES

TABLE A-1. FIBER LENGTH DISTRIBUTION IN THE
LOW CONCENTRATION AMPULE

Particle size range, μm	Number of fibers counted	Cumulative fiber count	Percent of total	Cumulative percent
0.23 - 0.34	0	0	0.00	0.00
0.34 - 0.54	0	0	0.00	0.00
0.50 - 0.73	107	107	17.29	17.29
0.73 - 1.08	147	254	23.75	41.03
1.08 - 1.58	106	360	17.12	58.16
1.58 - 2.32	90	450	14.54	72.70
2.32 - 3.41	69	519	11.15	83.84
3.41 - 5.00	57	576	9.21	93.05
5.00 - 7.34	26	602	4.20	97.25
7.34 - 10.77	11	613	1.78	99.03
10.77 - 15.81	5	618	0.81	99.84
15.81 - 23.21	0	618	0.00	99.84
23.21 - 34.06	1	619	0.16	100.00
34.06 - 50.00	0	619	0.00	100.00
50.00 - 73.40	0	619	0.00	100.00
73.40 - 107.70	0	619	0.00	100.00
107.70 - 158.10	0	619	0.00	100.00
158.10 - 232.10	0	619	0.00	100.00
232.10 - 340.60	0	619	0.00	100.00

TABLE A-2. FIBER LENGTH DISTRIBUTION IN THE
HIGH CONCENTRATION AMPULE

Particle size range, μm	Number of fibers counted	Cumulative fiber count	Percent of total	Cumulative percent
0.23 - 0.34	0	0	0.00	0.00
0.34 - 0.54	0	0	0.00	0.00
0.50 - 0.73	101	101	16.81	16.81
0.73 - 1.08	135	236	22.46	39.27
1.08 - 1.58	119	355	19.80	59.07
1.58 - 2.32	85	440	14.14	73.21
2.32 - 3.41	82	522	13.64	86.86
3.41 - 5.00	40	562	6.66	93.51
5.00 - 7.34	20	582	3.33	96.84
7.34 - 10.77	16	598	2.66	99.50
10.77 - 15.81	3	601	0.50	100.00
15.81 - 23.21	0	601	0.00	100.00
23.21 - 34.06	0	601	0.00	100.00
34.06 - 50.00	0	601	0.00	100.00
50.00 - 73.40	0	601	0.00	100.00
73.40 - 107.70	0	601	0.00	100.00
107.70 - 158.10	0	601	0.00	100.00
158.10 - 232.10	0	601	0.00	100.00
232.10 - 340.60	0	601	0.00	100.00

APPENDIX B

TOTAL AIRBORNE ASBESTOS STRUCTURE
CONCENTRATIONS BEFORE AND DURING
CARPET CLEANING FOR SAMPLES ANALYZED
BY TRANSMISSION ELECTRON MICROSCOPY

NOTE: Sample numbers ending with "B" indicate that the sample was taken before the experiment; those ending with "D" indicate that the sample was taken during the experiment.

Sample Number	Number of Asbestos Str.	Asbestos s/cm ³	Concentration, s/mm ²
EXPERIMENT 1 - WET CLEAN			
01-A442B	21	0.0809	170
01-A443B	25	0.0963	203
01-A444B	47	0.1810	381
01-A445D	25	0.0996	181
01-A446D	15	0.0597	109
01-A447D	19	0.0757	138
EXPERIMENT 2 - DRY VACUUM			
02-A448B	6	0.0234	49
02-A449B	57	1.2596	2617
02-A450B	12	0.0468	97
02-A451D	2	0.0070	12
02-A452D	6	0.0209	36
EXPERIMENT 3 - DRY VACUUM			
03-A454B	9	0.0349	73
03-A455B	7	0.0271	57
03-A456B	22	0.0853	178
03-A457D	53	0.5507	913
03-A458D	44	0.3658	606
03-A459D	50	0.3464	574
EXPERIMENT 4 - WET CLEAN			
04-A460B	4	0.0154	32
04-A461B	2	0.0078	16
04-A462B	5	0.0194	41
04-A463D	39	0.1309	234
04-A464D	37	0.1242	222
04-A465D	44	0.1477	264

Sample Number	Number of Asbestos Str.	Asbestos Concentration, s/cm ³	Asbestos Concentration, s/mm ²
EXPERIMENT 5 - WET CLEAN			
05-A466B	2	0.0073	15
05-A467B	6	0.0220	.44
05-A468B	1	0.0037	7
05-A469D	28	0.1004	276
05-A470D	28	0.1004	276
05-A471D	11	0.0392	108
EXPERIMENT 6 - DRY VACUUM			
06-A472B	6	0.0212	44
06-A473B	13	0.0465	94
06-A474B	8	0.0286	58
06-A475D	15	0.0523	90
06-A476D	15	0.0511	90
06-A477D	37	0.1235	222
EXPERIMENT 7 - DRY VACUUM			
07-A478B	26	0.1008	211
07-A479B	20	0.0770	162
07-A480B	24	0.0924	195
07-A481D	48	0.1828	315
07-A482D	57	0.2758	491
07-A483D	51	0.3291	586
EXPERIMENT 8 - WET CLEAN			
08-A484B	37	0.1399	300
08-A485B	38	0.1446	308
08-A486B	49	0.2453	519
08-A487D	53	0.3046	664
08-A488D	51	0.2703	586
08-A489D	48	0.2575	551

Sample Number	Number of Asbestos Str.	Asbestos Concentration, s/cm ³	Concentration, s/mm ²
EXPERIMENT 9 -WET CLEAN			
09-A490B	32	0.1265	315
09-A491B	23	0.0854	211
09-A492B	41	0.1523	377
09-A493D	51	0.2211	502
09-A494D	53	0.2171	487
09-A495D	51	0.2063	468
EXPERIMENT 10 - DRY VACUUM			
10-A496B	52	0.3656	895
10-A497B	52	0.2909	716
10-A498B	54	0.3375	827
10-A499D	57	0.3871	785
10-A500D	51	0.4891	1004
10-A501D	2	0.0071	15
EXPERIMENT 11 - DRY VACUUM			
11-A502B	6	0.0217	55
11-A503B	9	0.0326	83
11-A504B	21	0.0752	193
11-A505D	27	0.0981	219
11-A506D	47	0.1687	381
11-A507D	25	0.0898	203
EXPERIMENT 12 - WET CLEAN			
12-A508B	8	0.0288	74
12-A509B	5	0.0179	46
12-A510B	4	0.0143	37
12-A511D	17	0.0608	123
12-A512D	23	0.0823	167
12-A513D	23	0.0823	167

Sample Number	Number of Asbestos Str.	Asbestos Concentration, s/cm ²	s/mm ²
EXPERIMENT 13 - WET CLEAN			
13-A514B	22	0.0832	178
13-A515B	16	0.0601	130
13-A516B	19	0.0719	154
13-A517D	23	0.0804	186
13-A518D	51	0.2507	586
13-A519D	49	0.2251	519
EXPERIMENT 14 - DRY VACUUM			
14-A520B	42	0.1562	340
14-A521B	32	0.1190	259
14-A522B	42	0.1562	340
14-A523D	50	0.3177	530
14-A524D	50	0.3779	626
14-A525D	53	0.3368	562
EXPERIMENT 15 - DRY VACUUM			
15-A526B	20	0.0715	145
15-A527B	14	0.0500	102
15-A528B	9	0.0322	65
15-A529D	41	0.1482	246
15-A530D	33	0.1200	198
15-A531D	43	0.1571	258
EXPERIMENT 16 - WET CLEAN			
16-A532B	33	0.1271	267
16-A533B	8	0.0306	65
16-A534B	30	0.1156	243
16-A535D	52	0.1900	421
16-A536D	33	0.1199	267
16-A537D	43	0.1562	349

APPENDIX C

STRUCTURE LENGTH DISTRIBUTIONS OF AIRBORNE ASBESTOS BEFORE AND DURING CARPET CLEANING

TABLE C-1. FIBER LENGTH DISTRIBUTION OBSERVED IN
AIR SAMPLES COLLECTED BEFORE CARPET CLEANING

Particle size range, μm	Number of fibers counted	Cumulative fiber count	Percent of total	Cumulative percent
0.23 - 0.34	0	0	0	0
0.34 - 0.54	0	0	0	0
0.50 - 0.73	666	666	64.3	64.3
0.73 - 1.08	239	965	23.1	87.4
1.08 - 1.58	82	987	7.9	95.3
1.58 - 2.32	33	1020	3.2	98.5
2.32 - 3.41	9	1029	0.9	99.4
3.41 - 5.00	4	1033	0.4	99.8
5.00 - 7.34	1	1034	0.1	99.9
7.34 - 10.77	0	1034	0	99.9
10.77 - 15.81	1	1035	0.1	100
15.81 - 23.21	0	1035	0	100
23.21 - 34.06	0	1035	0	100
34.06 - 50.00	0	1035	0	100
50.00 - 73.40	0	1035	0	100
73.40 - 107.70	0	1035	0	100
107.70 - 158.10	0	1035	0	100
158.10 - 232.10	0	1035	0	100
232.10 - 340.60	0	1035	0	100

TABLE C-2. FIBER LENGTH DISTRIBUTION OBSERVED IN AIR SAMPLES
COLLECTED DURING DRY VACUUMING OF CARPET CONTAMINATED WITH THE
LOW-CONCENTRATION DISPERISON

Particle size range, μm	Number of fibers counted	Cumulative fiber count	Percent of total	Cumulative percent
0.23 - 0.34	0	0	0	0
0.34 - 0.54	0	0	0	0
0.50 - 0.73	238	238	63	63
0.73 - 1.08	104	342	27.5	90.5
1.08 - 1.58	24	366	6.3	96.8
1.58 - 2.32	5	371	1.3	98.1
2.32 - 3.41	4	375	1.1	99.2
3.41 - 5.00	2	377	0.5	99.7
5.00 - 7.34	1	378	0.3	100
7.34 - 10.77	0	378	0	100
10.77 - 15.81	0	378	0	100
15.81 - 23.21	0	378	0	100
23.21 - 34.06	0	378	0	100
34.06 - 50.00	0	378	0	100
50.00 - 73.40	0	378	0	100
73.40 - 107.70	0	378	0	100
107.70 - 158.10	0	378	0	100
158.10 - 232.10	0	378	0	100
232.10 - 340.60	0	378	0	100

TABLE C-3. FIBER LENGTH DISTRIBUTION OBSERVED IN AIR SAMPLES
COLLECTED DURING WET CLEANING OF CARPET CONTAMINATED WITH
THE LOW-CONCENTRATION DISPERSION

Particle size range, μm	Number of fibers counted	Cumulative fiber count	Percent of total	Cumulative percent
0.23 - 0.34	0	0	0	0
0.34 - 0.54	0	0	0	0
0.50 - 0.73	238	238	60.1	60.1
0.73 - 1.08	101	339	25.5	85.6
1.08 - 1.58	47	386	11.9	97.5
1.58 - 2.32	7	393	1.8	99.2
2.32 - 3.41	1	394	0.3	99.5
3.41 - 5.00	1	395	0.3	99.7
5.00 - 7.34	1	396	0.3	100
7.34 - 10.77	0	396	0	100
10.77 - 15.81	0	396	0	100
15.81 - 23.21	0	396	0	100
23.21 - 34.06	0	396	0	100
34.06 - 50.00	0	396	0	100
50.00 - 73.40	0	396	0	100
73.40 - 107.70	0	396	0	100
107.70 - 158.10	0	396	0	100
158.10 - 232.10	0	396	0	100
232.10 - 340.60	0	396	0	100

TABLE C-4. FIBER LENGTH DISTRIBUTION OBSERVED IN AIR SAMPLES
COLLECTED DURING DRY VACUUMING OF CARPET CONTAMINATED WITH
THE HIGH-CONCENTRATION DISPERSION

Particle size range, μm	Number of fibers counted	Cumulative fiber count	Percent of total	Cumulative percent
0.23 - 0.34	0	0	0	0
0.34 - 0.54	0	0	0	0
0.50 - 0.73	326	326	68.1	68.1
0.73 - 1.08	102	428	21.3	89.4
1.08 - 1.58	41	469	8.6	97.9
1.58 - 2.32	5	474	1.0	99.0
2.32 - 3.41	2	476	0.4	99.4
3.41 - 5.00	1	477	0.2	99.6
5.00 - 7.34	2	479	0.4	100
7.34 - 10.77	0	479	0	100
10.77 - 15.81	0	479	0	100
15.81 - 23.21	0	479	0	100
23.21 - 34.06	0	479	0	100
34.06 - 50.00	0	479	0	100
50.00 - 73.40	0	479	0	100
73.40 - 107.70	0	479	0	100
107.70 - 158.10	0	479	0	100
158.10 - 232.10	0	479	0	100
232.10 - 340.60	0	479	0	100

TABLE C-5. FIBER LENGTH DISTRIBUTION OBSERVED IN AIR SAMPLES
COLLECTED DURING WET CLEANING OF CARPET CONTAMINATED WITH
THE HIGH-CONCENTRATION DISPERSION

Particle size range, μm	Number of fibers counted	Cumulative fiber count	Percent of total	Cumulative percent
0.23 - 0.34	0	0	0	0
0.34 - 0.54	0	0	0	0
0.50 - 0.73	319	319	68	68
0.73 - 1.08	82	401	17.5	85.5
1.08 - 1.58	44	445	9.4	94.9
1.58 - 2.32	11	456	2.3	97.2
2.32 - 3.41	6	462	1.3	98.5
3.41 - 5.00	4	466	0.9	99.4
5.00 - 7.34	2	468	0.4	99.8
7.34 - 10.77	1	469	0.2	100
10.77 - 15.81	1	469	0	100
15.81 - 23.21	0	469	0	100
23.21 - 34.06	0	469	0	100
34.06 - 50.00	0	469	0	100
50.00 - 73.40	0	469	0	100
73.40 - 107.70	0	469	0	100
107.70 - 158.10	0	469	0	100
158.10 - 232.10	0	469	0	100
232.10 - 340.60	0	469	0	100

TECHNICAL REPORT DATA (Please read Instructions on the reverse before completing)		
1 REPORT NO	2	3 RECIPIENT'S ACCESSION NO.
4 TITLE AND SUBTITLE Asbestos Fiber Reentrainment During Dry Vacuuming and Wet Cleaning of Asbestos-Contaminated Carpet		5 REPORT DATE 7/31/89
		6 PERFORMING ORGANIZATION CODE
7 AUTHOR(S) John R. Kominsky, Ronald W. Freyberg		8 PERFORMING ORGANIZATION REPORT NO
9 PERFORMING ORGANIZATION NAME AND ADDRESS PEI Associates, Inc. 11499 Chester Road Cincinnati, OH 45246		10 PROGRAM ELEMENT NO
		11 CONTRACT/GRANT NO 68-03-4006
12 SPONSORING AGENCY NAME AND ADDRESS Risk Reduction Engineering Laboratory Office of Research and Development U.S. Environmental Protection Agency Cincinnati, OH 45268		13. TYPE OF REPORT AND PERIOD COVERED 1/88 - 7/89
		14. SPONSORING AGENCY CODE
15 SUPPLEMENTARY NOTES Project Officer: Thomas J Powers FTS: 684-7550 COMM: 569-7550		
16 ABSTRACT A study was conducted to evaluate the potential for asbestos fiber reentrainment during cleaning of carpet contaminated with asbestos. Two types of carpet cleaning equipment were evaluated at two carpet contamination levels. Airborne asbestos concentrations were determined before and during carpet cleaning. Overall, airborne asbestos concentrations were two to four times greater during the carpet cleaning activity. The level of asbestos contamination and the type of cleaning method used had no statistically significant effect on the relative increase of airborne asbestos concentrations during carpet cleaning. This document was submitted in fulfillment of Contract No. 68-03-4006 by PEI Associates, Inc., for the U.S. Environmental Protection Agency's Office of Research and Development, Risk Reduction Engineering Laboratory. This report covers a period of January 1988 to July 1989, and work was completed as of July 31, 1989.		
17 KEY WORDS AND DOCUMENT ANALYSIS		
a DESCRIPTORS	b IDENTIFIERS/OPEN ENDED TERMS	c COSATI Field/Group
18 DISTRIBUTION STATEMENT	19 SECURITY CLASS (This Report)	21 NO OF PAGES
	20 SECURITY CLASS (This page)	22 PRICE